ARMY RESEARCH LABORATORY

Investigating the Usefulness of Soldier Aids for Autonomous Unmanned Ground Vehicles, Part 2

by A William Evans III, Susan G Hill, Brian Wood, and Regina Pomranky

ARL-TR-7240 **March 2015**

NOTICES

Disclaimers

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5425

ARL-TR-7240 **March 2015**

Investigating the Usefulness of Soldier Aids for Autonomous Unmanned Ground Vehicles, Part 2

A William Evans III, Susan G Hill, and Regina Pomranky
Human Research and Engineering Directorate, ARL

Brian Wood
2DCS Corporation

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
March 2015	Final	October 2012

4. TITLE AND SUBTITLE	
Investigating the Usefulness of Soldier Aids for Autonomous Unmanned Ground Vehicles, Part 2	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
A William Evans III, Susan G Hill, Brian Wood, and Regina Pomranky	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. performing organization name(s) and address(es)	8. PERFORMING ORGANIZATION REPORT NUMBER
US Army Research Laboratory ATTN: RDRL-HRS-E Aberdeen Proving Ground, MD 21005-5425	ARL-TR-7240
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

DCS Corporation, Alexandria, VA

14. ABSTRACT

In the past, robot operation has been a high-cognitive-workload task requiring human operators to dedicate a large amount of their cognitive resources to maintaining awareness about a robot's state and functioning. This technical report describes research of operator-knowledge-management aids, in the form of visual display-screen overlays, used to help increase performance and reduce perceived workload. The aids were overlays displaying what an autonomous robot perceived in the environment and the subsequent course of action planned by the robot. Eight active-duty, US Army Soldiers completed 16 scenario missions using an operator interface called the Warfighter Machine Interface. The simulated missions included various display configurations, with combinations with and without 3 operator aids: Travel Planner, Obstacle Map, and Rerouting Alert. During the simulations, participants managed the autonomously navigating robot, taking teleoperation control when needed, while completing a reconnaissance to detect simulated improvised explosive devices. Results of this study showed that the use of operator aids resulted in less use of manual teleoperation control, suggesting that operators were better able to predict robot actions, understand the projected robot paths, and have less need to manually intervene in autonomous robot behavior. The use of operator aids did not, however, contribute to improved target detection.

15. SUBJECT TERMS

Operator aids, human–robot interaction, operator performance, workload

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON A William Evans
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (*Include area code*)
Unclassified	Unclassified	Unclassified	UU	48	410-278-5982

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

Acknowledgments

The research reported in this document was performed in connection with the Safe Operations for Unmanned Reconnaissance in Complex Environments (SOURCE) Army Technology Objective (ATO) for the US Army Research Laboratory.

INTENTIONALLY LEFT BLANK.

1. Introduction

As robots become more complex and autonomous, there are challenges in how to keep Soldiers informed about robot activity and intent and how to maintain overall mission effectiveness without increasing cognitive workload. Soldiers must be able to quickly gain an understanding of a robot's status when switching from one task to another task (e.g., switching between reconnaissance or a search for improvised explosive devices [IEDs] to area security or navigation). Soldiers will also need predictive capability about a robot's intended course of action so that corrective actions can be taken prior to encountering a situation in which it could prove difficult for the autonomy to handle without operator intervention. In this study, we investigated the usefulness of operator-knowledge-management aids, which overlay information about autonomous unmanned ground vehicles' (UGVs') perception and planned route execution onto existing user interfaces. These operator aids provide information visually and assist in cognitive tasks that involve understanding and projection of robot intent to follow planned travel paths.

The goal of this study was to continue to evaluate the extent to which operator performance and perceived workload is affected by operator aids. This is the second study looking at operator aids and measuring performance data, such as time to complete task and number of operator interventions (examples of task-dependent measures similar to those suggested by Fong et al. 2004). Workload was evaluated as a self-report measure using the NASA Task Load Index (TLX) (Hart and Staveland 1988). Additionally, operator-preference data were collected to evaluate which of the operator aids were preferred and why.

1.1 Background

In 2001, Jameson described the future Army's extensive use of mobile sensing systems, unmanned platforms, and decision-aiding systems. He also explained that information fusion would require an ability to create and maintain real-time situation awareness (SA) from all available information.

As described in this study, operator aids are one way to assist robotic operators in maintaining SA by quickly displaying mission-relevant information without taking too much attention from primary tasks. Operator aids are display tools that generate information from data supplied by the autonomous robot to provide an increased understanding of the robot's perceived environment and current and planned actions. The intent of operator aids is to reduce the cognitive workload by giving an operator information about a robot in a way that limits additional user cognitive processing and, at the same time, increases operator understanding. Wickens's Multiple Resource Theory (1980, 1984) suggests—and specifically for tasks with overlapping cognitive resources (i.e., vision-based tasks such as reconnaissance)—that as workload increases,

performance decreases. Therefore, in a human–robot team reconnaissance task with a number of highly visual components, it is expected that as workload increases, operator performance will decline.

Previous research (Mitchell et al. 2013, Mitchell 2008) similarly stated this expectation, predicting larger increases in workload for robot operators versus nonoperators because of the multiple, overlapping cognitive-resource requirements. We propose that the appropriate use of operator aids can mitigate some of the increased workload and performance decline by making explicit to the operator some of the information from the robot sensors as to current and future robot status and actions.

Research that explored shared mental models and their effect on team performance (Mathieu et al. 2000) provides a starting point for defining contributions that make human–robot teams more successful. One key is the ability among teammates to engage in predictive behaviors based on those shared mental models. Operator aids investigated here may support the development of a team environment in which human operators can predict robot behavior based on the additional information provided by the robot through the knowledge-management aids. Specifically, operator aids focus on information needed in order to supervise the robot and appropriately intervene to assist it. By informing the operator about what an autonomous robot calculates as its best route and why, the operator may anticipate situations that could be difficult for the autonomy to address successfully without operator intervention. Understanding the autonomous system's "intent" would allow the operator to make timely input to the robotic system when needed. It is believed that all of these outcomes will improve the human–system performance. Human performance, in this case, is defined by measures such as the amount of time spent in teleoperation mode and the number of times the operator engages manual-teleoperation mode. The less frequently, and less time, the operator is engaged in manual control, the more time will be available to the operator for primary operational tasks such as detecting IEDs. Operator aids are tools with which human workload related to manual-teleoperation control can be reduced—allowing more time, energy, and focus for other mission-critical tasks.

1.2 Hypotheses

Hypotheses for this study have been broken up into 1) those related to performance, and 2) those related to workload.

1) Two performance-related hypotheses were developed:

   H_1: Participants will identify simulated targets with greater accuracy in the experimental conditions than in the control condition.

   H_2: Participants will engage teleoperation control (also called "teleop") less often and for less time in the experimental conditions than in the control condition.

2) Two hypotheses were formulated in relationship to workload:

H_3: Participants will experience lower levels of perceived workload in the experimental conditions than in the control condition.

H_4: Participants' feedback will indicate a preference for operating a robot with operator aids as opposed to having no operator aids available.

2. Methodology

2.1 Experiment's Location and Technologies

2.1.1 Experiment's Location

The Operator Aid study took place at 2 locations at Marine Corps Base Camp Lejeune, North Carolina (Fig. 1) as part of Safe Operations for Unmanned Reconnaissance in Complex Environments Army Technology Objective (SOURCE ATO), a multiorganizational field-research and demonstration event. The SOURCE ATO event took place over several weeks and involved a number of organizations and technologies. Operator aids are one piece of this large research effort.

Fig. 1 Aerial view of the Camp Lejeune's MOUT facility: Soldiers participated in this experiment in both a classroom and a stationary Stryker vehicle. The simulated environment in the experiment was modeled in detail from this MOUT facility.

The 2 locations were an indoor classroom in the military operations in urban terrain (MOUT) facility for training and at an operator station located in the back of a specially equipped Stryker vehicle called the Crew-integration and Automation Test bed (CAT). The participants were seated in the vehicle commander's position within the CAT (Fig. 2).

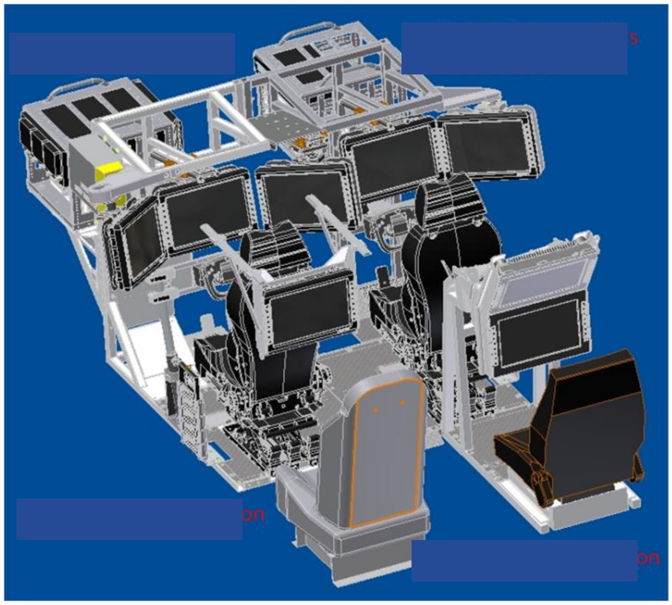


Fig. 2 Basic layout of control stations in the CAT Stryker: Soldier participants sat in the vehicle commander's station, front right. The work station included two 17-inch computer screens showing the simulated robot operations in Camp Lejeune's MOUT environment.

The Camp Lejeune MOUT facility was modeled as the simulation environment used for the robotic operations within this experiment.

2.1.2 Experiment's Technologies

This study used the ModSim simulation software developed by General Dynamics Robotics System (GDRS). This simulation was created as a visualization platform that serves as a basis for realistic simulated experimentation, validation, and refinement of hardware-in-the-loop dynamic planners. The virtual, 3-dimensional (3D) environment simulated was the streets and buildings of the Camp Lejeune MOUT facility. A simulated robot, called the Unmanned Ground Vehicle (UGV), operated within this environment. The simulation was used in conjunction with the US Army Tank Automotive Research, Development, and Engineering Center's Warfighter Machine Interface (WMI), developed by DCS Corp. The WMI is a user-interface system designed to accommodate a number of different technologies through the use of various computer-screen tabs to access the technologies. The operator aids are Travel Planner (TP), Obstacle Map (OM), and Rerouting Alert (RA). Examples of this WMI interface can be seen in Figs. 3–7.

Fig. 3 This example of the WMI interface shows 2 of the operator aids in the forward-facing (3D) view: TP (green line) and OM (red/green squares). The Operator Aids software was used while in the UGV technology tab (across the top). Other control capabilities were available on the touch-screen buttons located on the right and left of the screen.

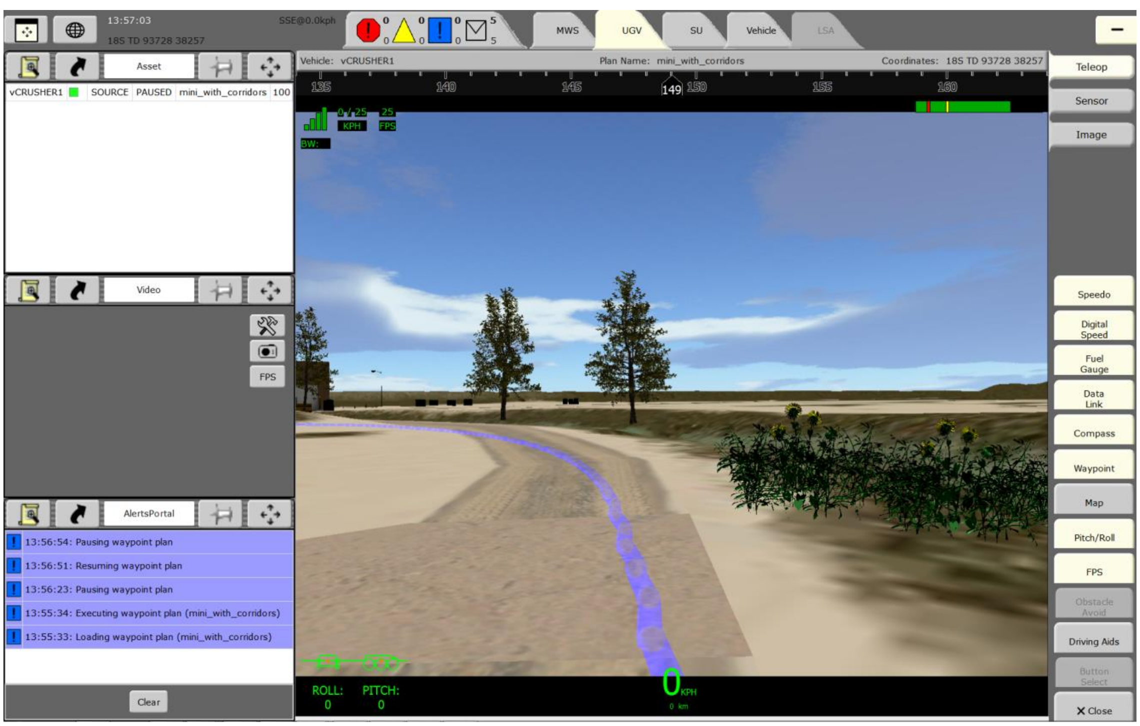


Fig. 4 This example of the WMI shows the TP (blue line) operator aid in the forward-facing (3D) view. The line is shown as completely blue, meaning the vehicle has stopped (also indicated by the speedometer in the bottom center of the screen).

Fig. 5 The WMI shows the OM overlay on a forward-facing 3D map. This is a ground-level view of the environment; red and green squares represent edges of obstacles. Red indicates obstacles that cannot be passed through (e.g., a wall); green represents obstacles that can potentially be traversed by the UGV (e.g., a tunnel).

Fig. 6 The WMI shows the OM overlay on a top-down, 2-dimensional (2D) map in an aerial view of the environment. The edges of obstacles are represented with red pixels; areas shaded gray are “unknown” because the view from the UGV is obstructed by the elements in the environment (e.g., a wall).

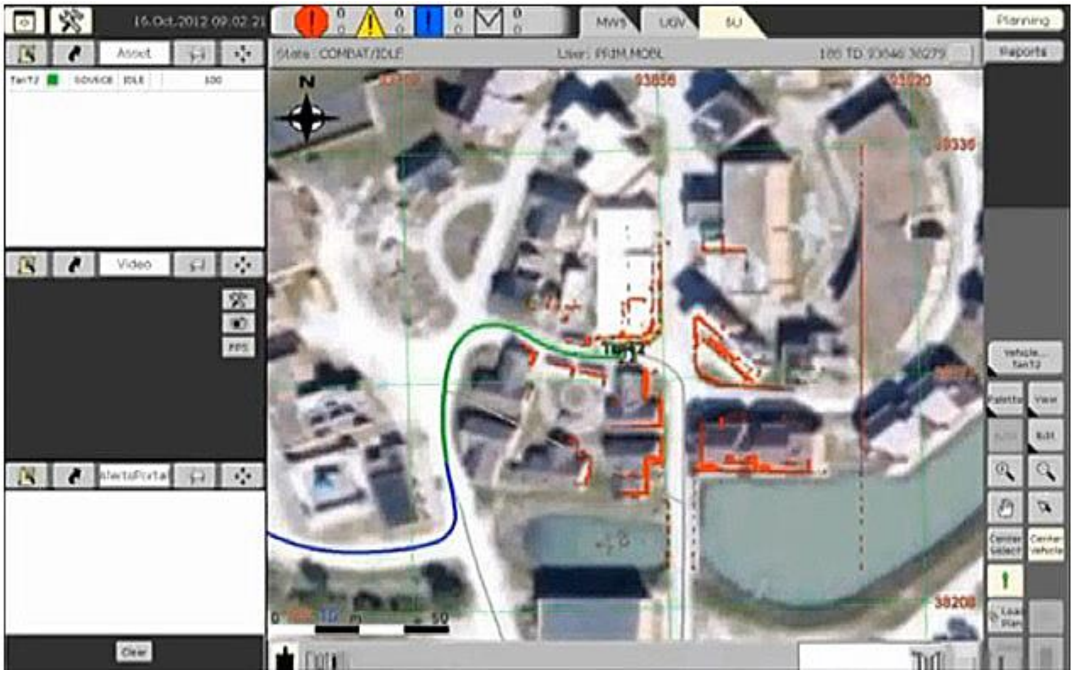


Fig. 7 Image from live video during the SOURCE ATO event: WMI shows TP (green and blue line) and OM (red and green pixels) in overhead (2D) view. The OM helps outline buildings/structures that might otherwise be obscured.

The WMI display has 2 screens showing different views of the environment. The forward-facing video display is referred to as the 3D driving display. This display shows a live, forward-facing feed of the environment directly in front of the UGV and allows for a ground-level “3D” view of the mission space. An overhead map view of the environment, referred to as the 2D map display, shows an overhead “satellite” view of the environment. The 2D view also gives users an indication of the UGV’s location within the mission space. Examples of the 2D portion of the WMI display can be seen in Figs. 6 and 7. The 2D and 3D screens were continuously displayed on two 17-inch monitors simultaneously so that participants could attend to either screen at any time during the experiment. Participants primarily monitored the forward-facing camera of the simulated UGV and entered task information using a touch-screen monitor. All of the software was run on standard personal computers, using two standard 17-inch color monitors with touch-screen capability.

Autonomous navigation for the simulated UGV was handled using the Autonomous Navigation System (ANS) software. This software was identical to the software used for a real-world version of the autonomous UGV and allowed the vehicle to navigate an environment via waypoint plan while avoiding environmental obstacles (GDRS 2013).

2.2 Participants

For this study, enlisted personnel, including noncommissioned officers, from the 594th Transportation Company were recruited as participants. A total of 8 individuals participated. Participants were all male with an average age of 27 years (standard deviation = 4.73). The 8 participants were all active-duty Soldiers with experience in infantry and motor-pool missions.

2.3 Materials and Tests

The experiment's participants were required to complete assessments of their color-vision acuity, spatial-visualization ability, and spatial-orientation ability as well as a demographic questionnaire that was used to characterize the participant population.

To assess color-vision acuity, the Ishihara (1917) color-vision test was used (see Appendix A) as a screening procedure. The color-vision test was used to ensure that participants have no unknown color-vision deficiencies, as color is an important component of the WMI and operator aids.

Two aspects of the Soldiers' spatial ability—spatial visualization and spatial orientation—were assessed using the relevant sections of the Guilford–Zimmerman (Guilford 1956) attribute survey (see Appendix B and Appendix C). Both of these assessments have been used previously in studies of human–robot interaction (HRI) (e.g., Fincannon et al. 2008), and have shown positive corollary effects with robot–operator performance. These results indicated that individuals displaying higher levels of spatial ability generally show higher levels of performance when engaging in HRI supervision tasks. The spatial-ability scores were used as covariates (as needed) in the data analysis for this study.

Participants' perceived workloads were evaluated after the completion of each mission scenario using the NASA-TLX questionnaire (Hart and Staveland, 1988; Appendix D). The NASA TLX is a self-report questionnaire of perceived demands in 6 areas: mental, physical, temporal, effort (mental and physical), frustration, and performance. Participants were asked to rate their perceived workload level in the 6 areas on 100-point scales. The ratings were used to quantify the perceived changes in workload for the various operator aids used.

Finally, participants' operator-aid configuration preference was recorded after each trial by asking each participant to identify their favorite and least favorite aid configurations.

2.4 Experimental Design

Participants in this study completed a series of reconnaissance missions in which they detected targets from a simulated autonomous UGV platform traversing within the simulated MOUT environment. Mission navigation of the UGV was fully autonomous; however, the UGV platform interface included a variety of operator aids intended to inform the operator about robot intent and robot obstacle identification. Participants took teleop (remote) control of the UGV only when it was encountering an obstacle (discussed further in Section 2.5 of this report).

This study employed a 2 (Travel Planner Condition) × 2 (Obstacle Map Condition) × 2 (Reroute Alert Condition) within subjects design (see Table 1). For analytical purposes, each experimental cell was compared with the control cell using paired sample *t*-tests. This analysis allowed researchers to understand if operator aids presented as a single aid or multiple aids contributed to improved performance over the condition involving no aids.

Table 1 Experimental Design Matrix. The design is a 2 × 2 × 2 within-subjects design, with Travel Planner, Reroute Alerts, and Obstacle Map overlays as the 3 independent variables. All 8 participants experienced all 8 conditions twice over 2 sessions spanning 2 days.

	With Travel Planner		**Without Travel Planner**	
	With Reroute Alerts	**Without Reroute Alerts**	**With Reroute Alerts**	**Without Reroute Alerts**
With Obstacle Map Overlays				
Without Obstacle Map Overlays				

2.4.1 Independent Variables

Travel Planner (TP), Obstacle Map (OM), and Rerouting Alert (RA) represent the 3 independent variables. Each of the independent-variable levels for the 3 Operator Aid conditions includes a “with” and “without” condition.

2.4.1.1 Travel Planner

The TP was adapted from a combination of the Short Term Planner and Long Term Planner used in an early laboratory study looking at operator aids (Evans 2013). In the previous study, the Short Term Planner visually showed the planned robot path for the next 3 to 5 seconds (s) and was shown as a green line. The Long Term Planner showed the robot path planned further out in time, such as in the next minutes, as a blue line. (See Fig. 8 for an example of each.) The TP for this experiment was adapted from the Long and Short Term Planners in response to users' recommendations of finding both the Long and Short Term Planners useful, but with concerns expressed about the overall amount of clutter on the screen obscuring view of the mission environment. The TP was represented by a green- and blue-colored translucent line overlaid on both forward-facing 3D driving display and 2D overhead-map display of the WMI. The translucent line extended out from the vehicle's position, providing information about where the vehicle intended to travel. The TP was generated using data from the ANS about the path which the automation is attempting to follow. The green portion of the line represented the path planned for the next 3–5 s, while the blue portion of the single translucent line conveyed the path planned further out in time. The actual length of the line was dependent upon vehicle speed and varied accordingly. See Figs. 3, 4, and 7 for examples of the TP display.

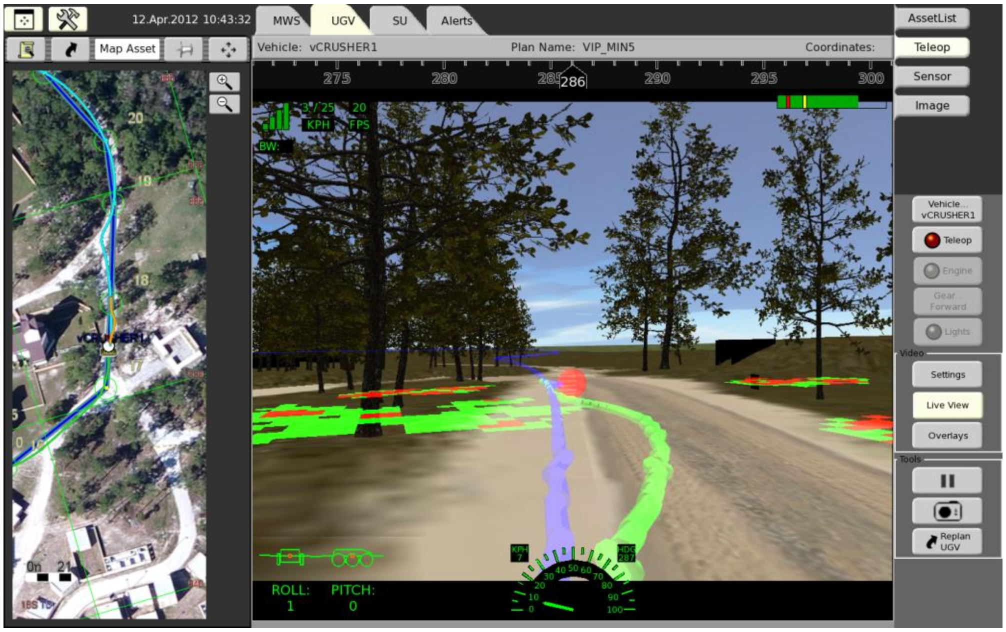


Fig. 8 Example of the original WMI 3D interface showing both the Short Term Planner (green line) and Long Term Planner (blue line) operator aids (Evans 2013). In response to user feedback that identified screen clutter as a concern, these 2 separate lines were combined into the single TP operator aid.

2.4.1.2 Obstacle Map

Obstacle maps were generated from Laser Radar data acquired by the ANS, which were then transformed to display the outlines of physical obstacles in the environment. Scenarios with the Obstacle Map included translucent overlays on both forward-facing (3D) video stream and overhead map (2D) views showing obstacles that the UGV has detected. On the 3D forward-facing view, the OM was represented by red (impassable obstacle) and green (passable obstacle) squares at ground level (see Figs. 3 and 5). For the 2D overhead view, OMs were represented using red pixels to show nonpassable obstacle borders and grey translucent shading to indicate unknown areas of the map (see Figs. 6 and 7). Overhead maps were pre-set at a fixed zoom scale to ensure that all participants received the same view. The overhead 2D-map view was not adjustable by the operator.

2.4.1.3 Rerouting Alert

The Rerouting Alert works much like the RA on commercially available GPS navigational systems. The autonomous UGV has a planned route upon which it intends to travel to get from point A to point B. Whenever the UGV diverges from that intended route (e.g., it makes a left turn rather than a right turn), a visual alert message will be produced that briefly displays on the forward-facing view screen of the WMI (see Fig. 9). The alert message is then placed into an alert-messaging cue which can be referenced at any time after the alert. During the conditions when an RA is present, an alert is only displayed visually, without audio cues.

Fig. 9 Example of the Rerouting Alert in use with the forward-facing (3D) view of the WMI: The UGV is changing its original route to maneuver around a perceived obstacle. RA shows briefly in a conspicuous location (center screen) in red to ensure saliency of the alert. Image was taken directly from live video recorded during the SOURCE ATO event.

2.4.2 Dependent Variables

Several types of dependent measures were seen as important for this study. Measures related to both performance and workload were used. The reconnaissance-mission scenarios had the primary performance measure of target detection. Measures related to teleoperation were also used. Although the UGVs are autonomous, there were times when operator intervention was necessary. The purpose of the operator aids was to provide current and future robot status and provide insights to the operator about the reasons for various robot actions. If the operator aids are helping the operator to better understand and anticipate UGV actions, it is thought that operator interventions (i.e., manual teleoperation) will be less frequent and will take less time than without the information provided by the operator aids. The less time the operator spends supervising the UGV through teleoperation, the more time there will be to conduct the primary task of IED detection.

Dependent variables for this study included 1) the number of accurate target detections, 2) the number of times engaging teleoperation mode, 3) the total amount of time spent in teleoperation mode, and 4) the total mission time. These are all variants of well-established metrics of performance used in HRI research (Fong et al. 2004). “Number of accurate target detections” is defined as the number of correct target locations selected on the overhead map during the performance mission. “Number of times engaging teleoperation mode” is defined as the total number of times the participant engages the teleoperation mode of UGV control during a

performance mission. (Teleoperation mode is engaged by a button control on the right side of the WMI display.) “Total time spent in teleoperation mode” is defined as the total amount of time in seconds that operators spent in teleoperation mode as opposed to autonomous mode. (Since teleoperation is engaged and disengaged with a button, an accurate time can be recorded.) “Total mission time” is defined as the total amount of time in seconds it takes to complete a mission beginning at the moment an automated route plan has begun executing until the completion of that plan, including all pauses and occurrences of teleoperation control. All of this information was gathered as *.log* files created for each mission. Time and frequency of occurrence data were obtained from the *.log* files and input into statistical software for further analysis.

The NASA TLX was used to measure ratings of perceived workload, resulting in an unweighted composite score derived from 6 areas of workload: mental, physical, temporal, effort, frustration, and performance. In addition, data were collected about participants’ spatial abilities (via the Guilford–Zimmerman Spatial Aptitude survey) to be used as covariates in data analysis. The spatial-ability covariate score was created by adding the scores from the 2 separate spatial-ability surveys (described in Section 2.3) together into a single composite score.

Finally, participants’ preferences for favorite and least favorite operator aid were recorded. These data were gathered by simply asking each participant at the end of the experiment “Which condition was your favorite?” and “Which condition was your least favorite?”

2.5 Procedure

Once an informed consent was completed, each Soldier participant was given the color-vision test. Any participant who exhibited any color vision impairment was removed from the study. Following this, each participant was given a demographic questionnaire to fill out. Finally, the participant was given the 2 assessments of spatial ability: one for spatial visualization and one for spatial orientation.

Each participant then was given a short tutorial on the use of the simulation interface and instructed on how to complete the reconnaissance task. The simulation was a representation of a UGV traversing a predetermined route within the MOUT simulated environment. The participant monitored the displays, searching for targets (represented as simulated IEDs—barrels with timers on them—that were not obscured from view) as the UGV traveled along the route.

The participant was given an opportunity to observe the 2D and 3D displays simultaneously and to use the simulation system in a practice scenario to become familiar with the system. This gave each participant an opportunity to review the various target and obstacle items that would be encountered during the experimental scenarios. The training session lasted about 2.5 h on the first day.

After familiarization and training, each participant was asked to act as operator for a UGV on a reconnaissance mission. Each participant completed 8 counterbalanced experimental scenarios twice for a total of 16 trials, exploring all of the possible independent variable combinations in

the 2 (TP Condition) × 2 (OM Condition) × 2 (RA condition) within subjects design, over the course of 2 experimental sessions of about 2 h each on consecutive days.

Each reconnaissance scenario consisted of one UGV following a predetermined route through the urban terrain. Along the route, the participant had the opportunity to detect up to 6 separate targets (i.e., simulated IEDs). In addition to scanning for targets, each participant monitored the UGV to ensure it remained on its intended path. Each mission included a set of obstacles (3 total) that caused the UGV's ANS to deviate from its planned path. These obstacles—patches of tall grass—were positioned randomly throughout the route. This obstacle type had been shown previously (Evans 2013) to cause the most inconsistent ANS behavior because it was the most difficult obstacle for the ANS to correctly interpret. In addition to the patches of grass that would cause a route deviation, distracter obstacles (also patches of grass) were included that would not cause any route deviations. Within the scenarios, the patches of tall grass represented ambiguous situations where the autonomy might incorrectly interpret the UGV's ability to proceed. In these cases, the operator aids might be most useful by helping the operator see and understand what the robot plans were with respect to obstacles and travel paths.

Participants were asked to choose an appropriate course of action (COA) whenever an obstacle was encountered. Two possible COAs were available: 1) let the UGV continue on its own with no operator intervention, or 2) the operator intervenes by using the teleoperation control to move the UGV around the obstacle and, once it is cleared, continue on the planned travel path by re-engaging the UGV's autonomous-navigation mode. When tall grass was encountered and caused a route deviation from the plan, the appropriate COA was to instruct the UGV to continue on the planned route without stopping, with no operator intervention (COA #1). COAs were executed by speaking aloud that an obstacle had been encountered and then operating the UGV with the appropriate maneuver for the obstacle, either "continue" or "teleoperation". At the end of each of the 16 scenarios, TLX data were collected to obtain a measure of perceived workload for that scenario. At the completion of all of the scenarios, user-preference data were collected via interview.

3. Performance Data Results and Analysis

To investigate the performance-related hypotheses (H_1 and H_2), an analysis of variance (ANOVA) was completed for each of the dependent variables. Within-subjects ANOVAs were conducted using SPSS 19.0 software (IBM 2013). Some of the data files were corrupted and these data points were eliminated via pairwise deletion. Results of the individual ANOVAs are presented in the following sections.

3.1 Target Detection

A within-subjects ANOVA was conducted to evaluate the effect of operator-aid condition on participants' ability to accurately detect targets in the experimental environment. Results of the ANOVA showed no significant differences in the experimental conditions ($F(7,98) = 1.986$, $p = .071$). To ensure that the individual difference factors related to spatial abilities were not influencing the analysis, covariate data were used in a follow-up analysis of covariance (ANCOVA). Covariates were derived from the 2 spatial ability evaluations: spatial orientation and spatial visualization. The covariates, representing an individual participant's spatial ability, were derived from the total number of correct answers for both spatial assessments, resulting in a composite spatial-ability score. The covariate analysis was used to control for spatial ability, since it is known that spatial ability is positively correlated with robotic-operator performance (Fincannon et al. 2008). Therefore, the results' failure to show differences in performance should be attributed to the experimental conditions (i.e., operator aids) and not to any differences in participants' innate abilities. The same approach for covariates was used for each of the performance-measure analysis (Sections 3.1–3.4). Results of the ANCOVA showed no significant influence from any of the covariates and no significant differences in the results ($F(7,97) = 0.537$, $p = .821$). The data from this analysis have been summarized in Table 2.

Table 2 Means and standard deviations for Target Detection data in the 8 conditions (measured in correct detections per mission; i.e., larger score is better; maximum is 6). No significant differences were found between conditions.

Dependent Variable: Target Detection		
Condition	**Mean**	**Standard Deviation**
C1: Travel Planner, Reroute Alert, & Obstacle Map	5.15	0.80
C2: Travel Planner & Obstacle Map	4.85	1.07
C3: Travel Planner & Reroute Alert	5.31	0.63
C4: Travel Planner only	5.62	0.51
C5: Reroute Alert & Obstacle Map	4.85	1.41
C6: Obstacle Map only	5.08	0.86
C7: Reroute Alert only	5.62	0.51
C8: No Operator Aids	5.38	0.87

3.2 Teleoperation Occurrences

A within-subjects ANOVA was conducted to evaluate the effect of operator-aid condition on participants' use of the teleoperation control mode in the experimental environment. Results of the ANOVA showed that significant main effect among the experimental conditions did exist ($F(7,98) = 3.261$, $p = .004$, $\eta^2 = .207$). The data from this analysis have been summarized in Table 3.

Table 3 Means and standard deviations for Teleoperation Occurrences in the 8 conditions are measured in number of times teleoperation mode was engaged per mission (i.e., smaller score is better, no maximum). Significant differences were found between conditions.

Dependent Variable: Teleoperation Occurrences		
Condition	**Mean**	**Standard Deviation**
C1: Travel Planner, Reroute Alert, & Obstacle Map	5.15	1.52
C2: Travel Planner & Obstacle Map	4.46	0.97
C3: Travel Planner & Reroute Alert	4.38	2.14
C4: Travel Planner only	4.23	1.09
C5: Reroute Alert & Obstacle Map	4.85	1.63
C6: Obstacle Map only	6.23	3.22
C7: Reroute Alert only	5.15	1.41
C8: No Operator Aids	6.85	1.46

Post hoc analysis, using pair-wise comparison with a Bonferroni correction, showed that 3 experimental conditions produced significantly lower numbers of teleoperation occurrences than the control condition: Condition 2 (Travel Planner and Obstacle Map), Condition 3 (Travel Planner and Reroute Alerts), and Condition 4 (Travel Planner only) were all significantly lower than the control condition (no aids) at the .05 level. No other results showed significance. These results are shown in Fig. 10, with the 3 conditions significantly lower (identified by the green arrows) than the control condition (identified by the red arrow).

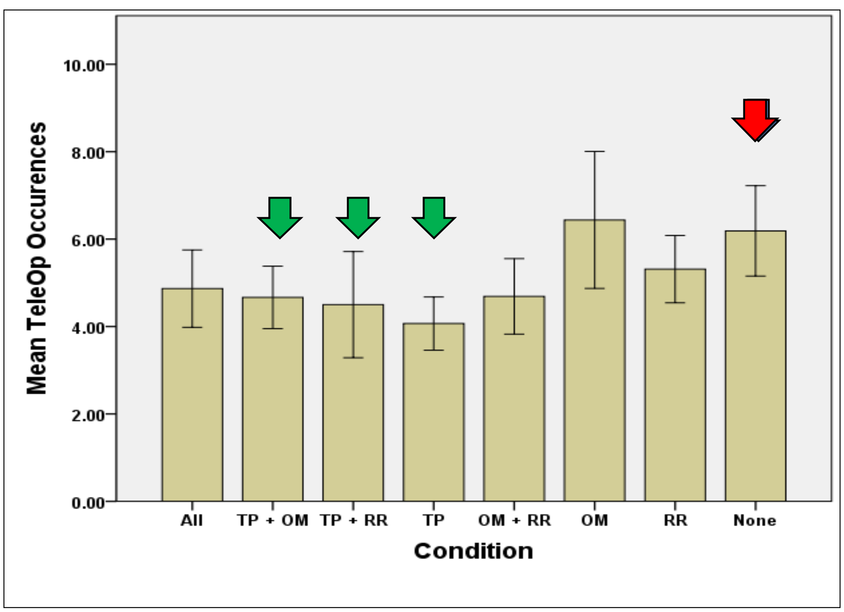


Fig. 10 Means plot for Teleoperation Occurrences by experimental condition: fewer teleoperation occurrences is interpreted as better performance. Note: "All" = Travel Planner (TP), Obstacle Map (OM), and Rerouting Alert (here, RR); "None" = Control—no operator aids.

3.3 Teleoperation Time

A within-subjects ANOVA was conducted to evaluate the effect of the operator-aid condition on participants' teleoperation-control times throughout the UGV's route in the experimental environment. Results of the ANOVA showed significant main effect did exist among the experimental conditions ($F(7,98)$ = 3.546, p = .003, η^2 = .279). The data from this analysis have been summarized in Table 4.

Table 4 Means and standard deviations for Teleoperation Time in the 8 conditions are measured in number of seconds per mission (i.e., smaller score is better). Significant differences were found between conditions.

Dependent Variable: Teleoperation Time		
Condition	**Mean**	**Standard Deviation**
C1: Travel Planner, Reroute Alert, & Obstacle Map	65.50	19.16
C2: Travel Planner & Obstacle Map	59.80	22.62
C3: Travel Planner & Reroute Alert	50.60	17.94
C4: Travel Planner only	55.60	18.51
C5: Reroute Alert & Obstacle Map	59.20	19.23
C6: Obstacle Map only	74.00	35.65
C7: Reroute Alert only	67.50	23.45
C8: No Operator Aids	111.20	70.41

Post hoc analysis showed the experimental conditions produced an average decrease of 49.5 s in amount of time spent in teleoperation mode when compared to the control (no aid) condition. Using paired sample *t*-tests and Tukey HSD corrections for Type I error, results showed that 5 of the experimental conditions (Conditions 1–5) had significantly lower time spent in teleoperation mode than the control:

- Condition 1—Travel Planner, Obstacle Map, and Reroute Alerts, $t(13)$ = 1.810, p = .048, one tailed;
- Condition 2—Travel Planner and Obstacle Map, $t(14)$ = 2.071, p = .028, one tailed;
- Condition 3—Travel Planner and Reroute Alerts, $t(13)$ = 2.186, p = .024, one tailed;
- Condition 4—Travel Planner only, $t(13)$ = 2.478, p = .014, one tailed; and,
- Condition 5—Obstacle Map and Reroute Alerts, $t(15)$ = 2.377, p = .016, one tailed.

No other results showed significance. These results are shown in Fig. 11, with the mean for the experimental conditions lower (identified by the green line) than the control condition (identified by the red line) by an average total of 49.5 s.

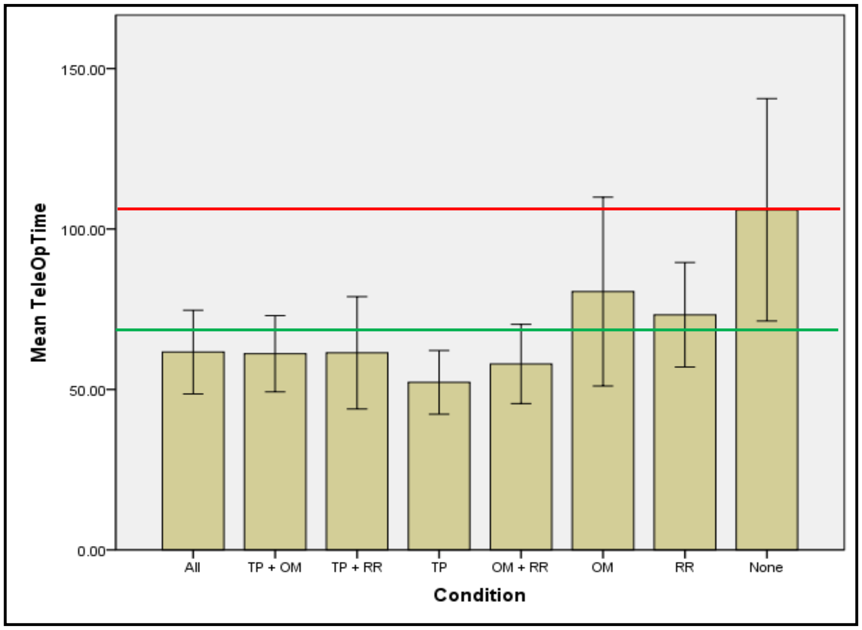


Fig. 11 Means plot for Total Teleoperation Time by experimental condition: green line represents the average time for all operator-aid conditions; red line shows the average time for the control condition. Difference between the red and green lines = 49.5 s. Note: "All" = Travel Planner (TP), Obstacle Map (OM), and Rerouting Alert (here, RR); "None" = Control—no operator aids.

3.4 Total Mission Time

Finally, a within-subjects ANOVA was conducted to evaluate the effect of operator-aid condition on overall mission time. Results of the ANOVA showed no significant differences in the experimental conditions ($F(7,113) = 0.937$, $p = .483$). To ensure that other factors were not influencing the analysis, covariate data were used in a follow-up ANCOVA analysis. Covariates were derived from the spatial-ability evaluations, and the analysis process was the same as described above. Results of the ANCOVA showed no significant influence from any of the covariates and no significant differences in the results ($F(7,112) = 0.697$, $p = .677$). The data from this analysis have been summarized in Table 5.

Table 5 Means and standard deviations for Total Mission Time data in the 8 conditions are measured in total seconds per mission, from beginning of automated plan's execution to completion of plan (i.e., less time is better). No significant differences were found between conditions.

Dependent Variable: Total Mission Time		
Condition	**Mean**	**Standard Deviation**
C1: Travel Planner, Reroute Alert, & Obstacle Map	514.69	125.69
C2: Travel Planner & Obstacle Map	525.08	137.45
C3: Travel Planner & Reroute Alert	518.85	117.58
C4: Travel Planner only	525.31	88.92
C5: Reroute Alert & Obstacle Map	508.08	68.40
C6: Obstacle Map only	574.69	164.55
C7: Reroute Alert only	544.85	95.70
C8: No Operator Aids	593.38	125.33

4. Workload Data Analysis

To investigate the workload hypothesis (H_3), comparisons of the experimental conditions were conducted using analysis of variance. The NASA-TLX composite scores were calculated by summing the 6 subscale scores and dividing by 6 (as suggested by Hill et al. 1992; highest possible score is 100). The composite scores were analyzed with a one-way ANOVA using SPSS 19.0. The composite scores reflected the self-reported workload score for each operator-aid condition. Results of the ANOVA showed no significant differences existed ($F(7,113) = 1.195$, $p = .311$) among the self-reported workload measures for the different operator-aid conditions. These results are in Table 6 and Fig. 12.

Table 6 Means and standard deviations for the composite NASA-TLX subjective workload are measured by experimental condition: maximum = 100, with lower ratings reflecting less workload. No significant differences were found.

Dependent Variable: Subjective Workload		
Condition	**Mean**	**Standard Deviation**
C1: Travel Planner, Reroute Alert, & Obstacle Map	38.32	12.17
C2: Travel Planner & Obstacle Map	38.81	11.37
C3: Travel Planner & Reroute Alert	38.53	10.06
C4: Travel Planner only	40.30	8.97
C5: Reroute Alert & Obstacle Map	42.47	12.40
C6: Obstacle Map only	41.32	12.81
C7: Reroute Alert only	41.68	14.02
C8: No Operator Aids	39.41	11.28

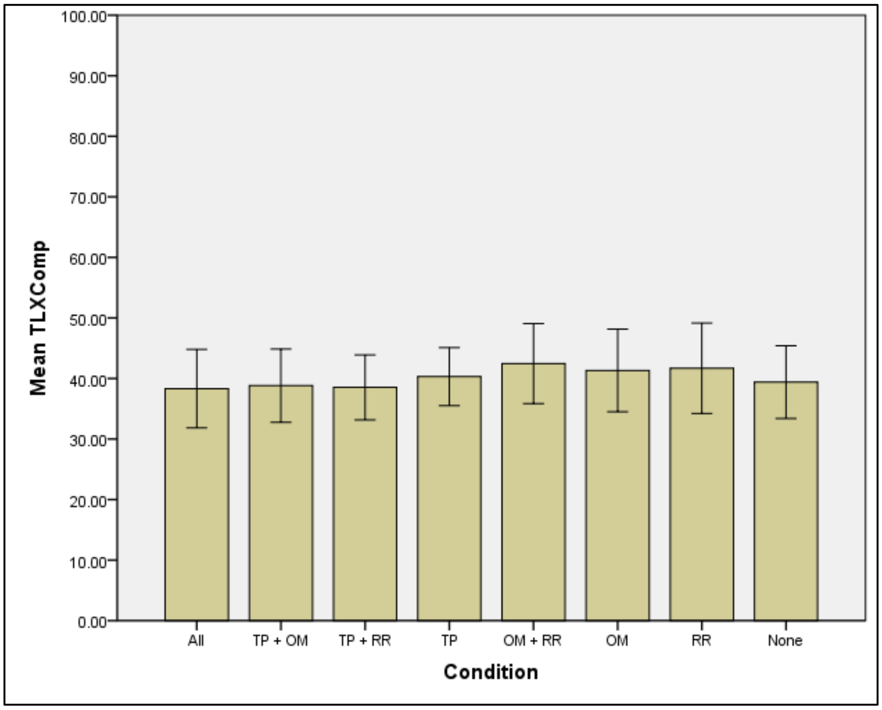


Fig. 12 Means plot for NASA-TLX workload composite scores by experimental condition: range of possible scores is 0–100. There are no significant differences among conditions. Note: “All” = Travel Planner (TP), Obstacle Map (OM), and Rerouting Alert (here, RR); “None” = Control—no operator aids.

5. User-Preference Data Analysis

5.1 Operator Aid Condition

Participants were asked which of the conditions were their favorite and least favorite to use (the post-study interview questions described in Section 2.4.2). While the choices for favorite condition were more varied, the majority of the choices (by 5 of the 8 participants) were for experimental conditions involving the Travel Planner operator aid. Additionally, half (4 of 8) listed the control condition with “no operator aids” as their least favorite. (See Table 7.)

Table 7 Frequency of responses for participants' favorite and least favorite operator-aid configurations (n = 8).

Dependent Variable: User Preferences		
Conditions:	**Favorite Condition No. of Responses n=8**	**Least Favorite Condition No. of Responses n=8**
C1: Travel Planner, Reroute Alert, & Obstacle Map	1	0
C2: Travel Planner & Obstacle Map	1	0
C3: Travel Planner & Reroute Alert	1	0
C4: Travel Planner only	2	2
C5: Reroute Alert & Obstacle Map	0	0
C6: Obstacle Map only	3	0
C7: Reroute Alert only	0	2
C8: No Operator Aids	0	4

When asked about their choices and what influenced them, the Soldiers' most common concern was clutter on the interface. The Soldiers involved in this study were very clear that too many operator aids could obscure their view of the environment. The Soldiers emphasized they extracted as much information as possible from a single aid. This is represented in the choice of a single-aid condition as the favorite for 5 of the 8 participants.

6. Discussion

6.1 Performance

Results of the performance-data analysis support the hypothesis related to teleoperation-mode use (H_2). Participants used teleoperation controls less frequently and for less time in the experimental conditions than in the control condition. Therefore, it appears that the participants were able to choose the most appropriate COA and allow the autonomy to continue to operate when appropriate in the experimental conditions; the participant operators did not preemptively use teleoperation control. This suggests that operators were able to more accurately predict the behavior of robotic assets when provided with additional robotic intent information. The scenarios for this study were relatively short (about 10 min). We speculate that for longer missions, this finding—reduction of time in direct control of a robotic asset means more time (and potentially more cognitive resources) for the operator to focus on the primary target-detection task—could be even more significant.

However, the hypothesis that the primary task of detecting targets would improve with the use of operator aids (H_1) was not supported. This failure to observe more target detections with the use of operator aids may be due to several factors. A relatively small sample size (n = 8) and low workload task could have affected results. The task of supervising a single robot without additional tasks allowed the participants to focus a large amount of their attention on the primary task (target detection). Including a demanding secondary task (such as radio communication) or

an increase in the number of assets (i.e., robots or other tactical assets) being supervised would be expected to cause higher workload. Operator aids may have a greater positive performance effect in higher-workload conditions. Additionally, participants in this study received limited training and were exposed to the operator aids for a relatively short amount of time during the data-collection scenarios. More training and exposure might help users understand more "strategic" uses for the operator aids—such as, using the Obstacle Map to help identify potential target locations—rather than just to understand what the robot sensors are observing. Developing a strategy for the use of operator aids could potentially improve overall performance.

6.2 Workload

Results of the workload-data analysis did not support the hypothesis (H_3) associated with the perceived workload measurements. Participants did not show any significant difference in perceived workload between the experimental and control conditions. This failure to observe any significant differences may be due to several factors. The relatively small sample size (n = 8) and simple task (i.e., looking for IEDs that were not obscured from view) could have affected results. Additionally, we observed that the Soldiers who participated in this study may have experienced some testing fatigue, which perhaps led to a smaller range of (i.e., less contrasting) perceptions on the NASA-TLX workload survey. The workload-survey results suggest that some participants began repeating survey answers for each scenario rather than providing more thoughtful and condition-specific perceptions of workload. It should be noted that while the use of operator aids did not reduce perceived workload, neither did the inclusion of aids increase the participants' perceived workload.

Further, the overall workload results remained relatively low across conditions throughout the study. This suggests that the task itself may have been not challenging enough to produce significant workload challenges for the participants. If the task was too easy, it may explain why the covariate measures, which have been shown to be significant in previous studies, did not yield any significant results here. That is, all participants could perform the tasks well, regardless of their individual spatial ability (which in this case could be considered average overall). In future studies, task difficulty should be advanced to levels that ensure an appropriate amount of workload so that "floor effects", such as those noted here, are not a factor. This would likely be achieved by including more mission-relevant secondary tasks or increasing the number of robots controlled. Including more secondary tasks could reduce the amount of cognitive resources available to be allocated to both primary and secondary tasks, in turn increasing the overall effort required to maintain performance levels. If the overall effort is high, the introduction of operator aids may provide more benefit to performance than if the overall effort is considered low.

6.3 User Preference

The user-preferences data addressing the preferences hypothesis (H_4) indicated that operators preferred having information coming from one or more aids to help them gain a complete understanding of the situation. Five of the 8 participants showed a preference for conditions that included the Travel Planner. Four of the 8 participants preferred conditions with the Obstacle Map. Interestingly, 5 of the 8 participants preferred conditions which included only one of the operator aids. The most frequent reason for this preference was a concern about clutter on the screen and the potential to obscure critical information from the user. This is valuable feedback that reinforces the decision made, based on results of a prior study (Evans 2013), to combine the Short Term and Long Term planners into the single Travel Planner aid that was used in this current study. Additionally, preference data add another source of information when considering future adaptations of the current operator aids. An example of this would be to provide aids with a more translucent, see-through presentation so as to minimize the occlusion of objects present in the environment behind the aids' overlay displays.

7. Conclusions

These study results suggest that information about robot intent can be inferred through the use of operator aids. The operator aids allowed the participants to adjust their mental model of what actions the robot would take based on the travel plan, obstacle map, and rerouting alerts displayed. In fact, it was with the Travel Planner aid that operators showed the most consistent improvements in performance across the measured variables. Knowing what actions the robot had planned may have allowed the participants to predict both the robot's movements and the outcome of those movements. By engaging the teleoperation mode less frequently, we assume, the operators can devote a larger portion of their attention and focus on the primary task of target detection. However, more extensive training and development of strategies in the use of the aids may also help to realize improvements in performance.

Another related area of interest is trust (Hancock et al. 2011, Freedy et al. 2007). Operator aids may be one method that can be used to assist Soldiers in appropriately calibrating trust in robot technology. By having interfaces that build, or take advantage of, shared mental models within the human–robot team, and provide transparency into the reasoning and intent of the robots, Soldiers may have a greater understanding of the robot and its inner workings. It is posited that a greater understanding of the robot's reasoning will contribute positively to trust and to performance—this is currently an active area of research.

8. References

Barnes M, Jentsch F, Chen JYC, Haas H, Cosenzo K. Soldier-robot teams: six years of research. Proceedings of the 54th Annual Meeting of the Human Factors and Ergonomics Society; 2010 Sep 27–Oct 1; San Francisco (CA).

Evans AW. Investigating the usefulness of operator aids for autonomous unmanned ground vehicles performing reconnaissance tasks. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2013 Sep. Report No.: ARL-TR-6651. Also available at http://dtic.mil/dtic/tr/fulltext/u2/a587692.pdf .

Fincannon T, Evans AW, Jentsch F, Keebler J. Interactive effects of backup behavior and spatial abilities in the prediction of teammate workload using multiple unmanned vehicles. Proceedings of the 52nd Annual Meeting of the Human Factors and Ergonomics Society; 2008 Sep 22–26; New York (NY).

Fong T, Kaber D, Lewis M, Scholtz J, Shultz A, Steinfeld A. Common metrics for human-robot interaction. In: Proceedings of IEEE International Conference on Intelligent Robots and Systems; 2004 Sep 28–Oct 2; Sendai (Japan).

Freedy A, de Visser E, Weltman G, Coeyman N. Measurement of trust in human-robot collaboration. In: Proceedings of the 2007 International Symposium on Collaborative Technologies and Systems; 2007 May 21–25; Orlando (FL): IEEE; p. 106–114.

General Dynamics Robotic Systems. 2014 [accessed 2014 Dec 17]. http://www.gdrs.com/programs/program.asp?UniqueID=22.

Guilford JP. The Guilford-Zimmerman aptitude survey. Pers Guid J. 1956;35(4):219–223.

Hancock PA, Billings DR, Oleson KE, Chen JYC, DeVisser E, Parasuraman R. A meta-analysis of factors impacting trust in human-robot interaction. Hum Fact. 2011;53(5):517–527.

Hart S, Staveland L. Development of NASA TLX (Task Load Index): Results of empirical and theoretical research. In: Hancock P, Meshkati N, editors. Human mental workload. Elsevier (Amsterdam); 1988. p. 139–183.

Hill S, Iavecchia H, Byers J, Bittner A, Zaklad A, Christ R. (1992). Comparison of four subjective workload rating scales. Hum Fact. 1992;34(4):429–439.

IBM SPSS software. 2014 [accessed 2014 Dec 18] http://www-1.ibm.com/software/analytics/spss

Ishihara, S. 1917. Color vision test (partial example). 2014 [accessed 2014 Dec 18]. http://www.toledo-bend.com/colorblind/Ishihara.asp .

Jameson S. Architectures for distributed information fusion to support situation awareness on the digital battlefield. In: Proceedings of the 4th International Conference on Data Fusion; 2001.

Mathieu J, Heffner T, Goodwin G, Salas E, Cannon-Bowers J. The influence of shared mental models on team process and performance. J App Psychol. 2000;85(2):273–283.

Mitchell DK. Predicted impact of an autonomous navigation system (ANS) and crew-aided behaviors (CABs) on Soldier workload and performance. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2008. Report No.: ARL-TR-4342.

Mitchell DK, Brennan G, Lobo B. Workload analyses of reconnaissance vehicle commander: with and without robotic asset responsibilities. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2013. Report No.: ARL-TR-6607.

Sellers B, Fincannon T, Jentsch F. The effects of autonomy and cognitive abilities on workload and supervisory control of unmanned systems. Proceedings of the 56nd Annual Meeting of the Human Factors and Ergonomics Society; 2012 Oct 22–26; Boston (MA).

Wickens CD. The structure of attentional resources. In: Nickerson R, editor. Attention and performance VIII. Hillsdale (NJ): Erlbaum; 1980. p. 239–257.

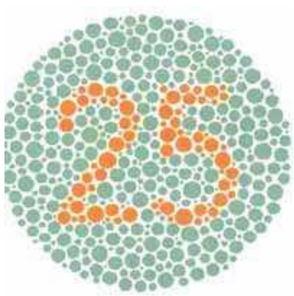
Wickens CD. Processing resources in attention. In: Parasuraman R, Davies DR, editors. Varieties of attention. New York (NY): Academic Press; 1984. p. 63–102.

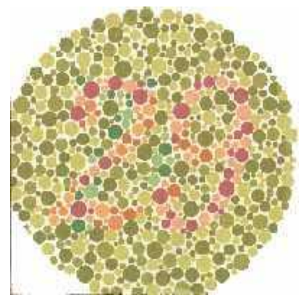
Appendix A. Examples of Ishihara Color-Vision Assessment

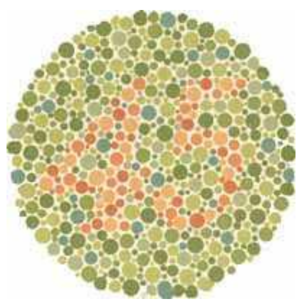
This appendix appears in its original form, without editorial change.

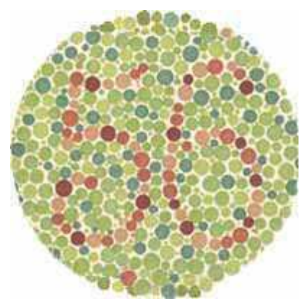
Color Vision Test

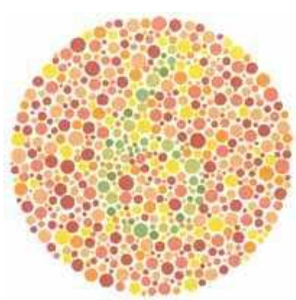
What numbers do you see revealed in the patterns of dots below? Please record the number on the answer sheet or, if you do not see a number, write “NONE.”

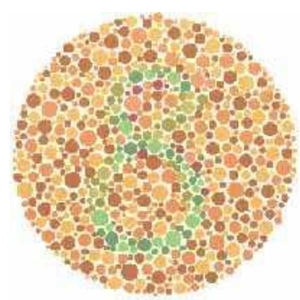
Question 1 

Question 2 

Question 3 

Question 4 

Question 5 

Question 6 

Please turn the page to continue. . .

Appendix B. Example of Guilford–Zimmerman Spatial Visualization Assessment

This appendix appears in its original form, without editorial change.

The Guilford-Zimmerman Aptitude Survey

Part 6/Spatial Visualization

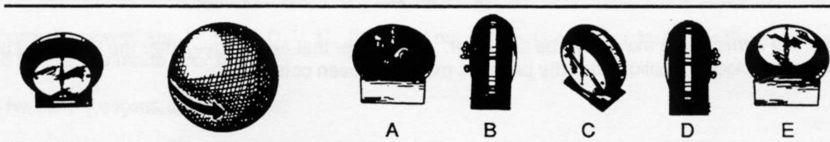
Name ____________________ Date _______ Score _______ Sex: M F

INSTRUCTIONS.

This is a test of how well you are able to visualize spatial position. In each item you are to note how the clock would move if it were moved as indicated by the arrow on the sphere.

Here are some sample items.

I



The first picture at the left shows a clock. Next to it is a sphere with an arrow marked on it. The arrow shows how the clock is to be moved. This move is illustrated (in two steps) in the picture below. When the clock is moved to the one-quarter turn shown by the arrow, it is then in position B. B is therefore the correct answer. You would record this by darkening the answer space right below B on your answer sheet. (But do not record answers to sample items.)

Consulting Psychologists Press, Inc., 3803 E. Bayshore Road, Palo Alto, California 94303

Printed in the United States of America. 02 01 00 99 11 10 9 8

0041R

Appendix C. Example of Guilford–Zimmerman Spatial Orientation Assessment

This appendix appears in its original form, without editorial change.

The Guilford-Zimmerman Aptitude Survey

Part 5/Spatial Orientation

Name ____________________ Date ________ Score ________ Sex: M F

INSTRUCTIONS.

This is a test of your ability to see changes in direction and position. In each item you are to note how the position of the boat has changed in the second picture from the original position in the first picture.

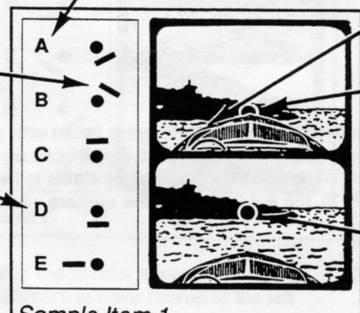
Here is Sample Item 1.

These are the five possible answers to the item.

These bars represent the boat's prow.

This is the correct answer. It shows that the prow of the boat has dropped below the aiming point.

(If the prow had risen, instead of dropped, the correct answer would have been C, instead of D.)



Sample Item 1

This is the prow (front end) of a motor boat in which you are riding.

This is the aiming point. It is the exact spot you would see on land if you sighted right over the point of the prow.

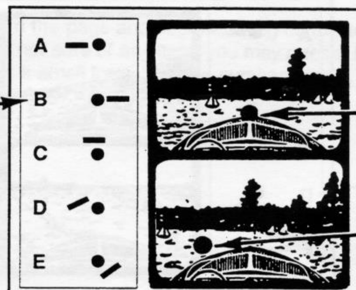
This is the same aiming point shown above. Note that the prow has dropped below it.

To work each item: **First**, look at the top picture and see where the motor boat is headed. **Second**, look at the bottom picture and note the CHANGE in the boat's heading. **Third**, mark the answer that shows the same change on the separate answer sheet.

Try Sample Item 2.

This also shows that the prow of the boat is to the right of the aiming point. So, it is the correct answer.

(If the boat had turned to the left, instead of to the right, the correct answer would have been A.)



Sample Item 2

This is the aiming point.

This is the same aiming point. The motor boat is now headed to the right of it.

Consulting Psychologists Press, Inc., 3803 E. Bayshore Road, Palo Alto, California 94303

Printed in the United States of America. 03 02 01 00 99 14 13 12 11

0039

Appendix D. Example of NASA-TLX Perceived Workload Assessment

This appendix appears in its original form, without editorial change.

RATING SCALE DEFINITIONS

TITLE	**ENDPOINTS**	**DESCRIPTIONS**
MENTAL DEMAND	LOW/HIGH	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	LOW/HIGH	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	LOW/HIGH	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	GOOD/POOR	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	LOW/HIGH	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	LOW/HIGH	How insecure, discouraged, irritated stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

Scoring Form 1

1. **Mental Demand - Individual**

Low High

2. **Physical Demand - Individual**

Low High

3. **Temporal Demand - Individual**

Low High

4. **Performance - Individual**

Good Bad

5. **Effort - Individual**

Low High

6. **Frustration - Individual**

Low High

INTENTIONALLY LEFT BLANK.

List of Symbols, Abbreviations, and Acronyms

ANCOVA	analysis of covariance
ANOVA	analysis of variance
ANS	Autonomous Navigation System
ATO	Army Technology Objective
CAT	Crew-integration and Automation Test bed
COA	course of action
GDRS	General Dynamics Robotics System
GPS	global positioning system
HRI	human–robot interaction
IED	improvised explosive device
MOUT	military operations in urban terrain
OM	Obstacle Map
RA	Rerouting Alert
s	second
SA	situational awareness
SOURCE	Safe Operations for Unmanned Reconnaissance in Complex Environments
3D	3-dimensional
TLX	Task Load Index
TP	Travel Planner
2D	2-dimensional
UGV	Unmanned Ground Vehicle
WMI	Warfighter Machine Interface

1 (PDF) DEFENSE TECHNICAL
INFORMATION CTR
DTIC OCA

2 (PDF) DIRECTOR
US ARMY RESEARCH LAB
RDRL CIO LL
IMAL HRA MAIL & RECORDS
MGMT

1 (PDF) GOVT PRINTG OFC
A MALHOTRA

1 (PDF) ARMY RSCH LABORATORY – HRED
RDRL HRM D
T DAVIS
BLDG 5400 RM C242
REDSTONE ARSENAL AL 35898-7290

1 (PDF) ARMY RSCH LABORATORY – HRED
RDRL HRS EA DR V J RICE
BLDG 4011 RM 217
1750 GREELEY RD
FORT SAM HOUSTON TX 78234-5002

1 (PDF) ARMY RSCH LABORATORY – HRED
RDRL HRM DG J RUBINSTEIN
BLDG 333
PICATINNY ARSENAL NJ 07806-5000

1 (PDF) ARMY RSCH LABORATORY – HRED
ARMC FIELD ELEMENT
RDRL HRM CH C BURNS
THIRD AVE BLDG 1467B RM 336
FORT KNOX KY 40121

1 (PDF) ARMY RSCH LABORATORY – HRED
AWC FIELD ELEMENT
RDRL HRM DJ D DURBIN
BLDG 4506 (DCD) RM 107
FORT RUCKER AL 36362-5000

1 (PDF) ARMY RSCH LABORATORY – HRED
RDRL HRM CK J REINHART
10125 KINGMAN RD BLDG 317
FORT BELVOIR VA 22060-5828

1 (PDF) ARMY RSCH LABORATORY – HRED
RDRL HRM AY M BARNES
2520 HEALY AVE
STE 1172 BLDG 51005
FORT HUACHUCA AZ 85613-7069

1 (PDF) ARMY RSCH LABORATORY – HRED
RDRL HRM AP D UNGVARSKY
POPE HALL BLDG 470
BCBL 806 HARRISON DR
FORT LEAVENWORTH KS 66027-2302

1 (PDF) ARMY RSCH LABORATORY – HRED
RDRL HRM AT J CHEN
12423 RESEARCH PKWY
ORLANDO FL 32826-3276

1 (PDF) ARMY RSCH LAB – HRED
HUMAN SYSTEMS
INTEGRATION ENGR
TACOM FIELD ELEMENT
RDRL HRM CU P MUNYA
6501 E 11 MILE RD
MS 284 BLDG 200A
WARREN MI 48397-5000

1 (PDF) ARMY RSCH LABORATORY – HRED
FIRES CTR OF EXCELLENCE
FIELD ELEMENT
RDRL HRM AF C HERNANDEZ
3040 NW AUSTIN RD RM 221
FORT SILL OK 73503-9043

1 (PDF) ARMY RSCH LABORATORY – HRED
RDRL HRM AV W CULBERTSON
91012 STATION AVE
FORT HOOD TX 76544-5073

1 (PDF) ARMY RSCH LABORATORY – HRED
RDRL HRM DE A MARES
1733 PLEASONTON RD BOX 3
FORT BLISS TX 79916-6816

8 (PDF) ARMY RSCH LABORATORY – HRED
SIMULATION & TRAINING
TECHNOLOGY CENTER
RDRL HRT COL G LAASE
RDRL HRT I MARTINEZ
RDRL HRT T R SOTTILARE
RDRL HRT B N FINKELSTEIN
RDRL HRT G A RODRIGUEZ
RDRL HRT I J HART
RDRL HRT M C METEVIER
RDRL HRT S B PETTIT
12423 RESEARCH PARKWAY
ORLANDO FL 32826

1 (PDF) ARMY RSCH LABORATORY – HRED
HQ USASOC
RDRL HRM CN R SPENCER
BLDG E2929 DESERT STORM DRIVE
FORT BRAGG NC 28310

1 (PDF) ARMY G1
DAPE MR B KNAPP
300 ARMY PENTAGON RM 2C489
WASHINGTON DC 20310-0300

ABERDEEN PROVING GROUND

12 (PDF) DIR USARL
RDRL HR
L ALLENDER
P FRANASZCZUK
K MCDOWELL
RDRL HRM
P SAVAGE-KNEPSHIELD
RDRL HRM AL
C PAULILLO
RDRL HRM B
J GRYNOVICKI
RDRL HRM C
L GARRETT
RDRL HRS
J LOCKETT
RDRL HRS B
M LAFIANDRA
RDRL HRS D
A SCHARINE
RDRL HRS E
A EVANS
D HEADLEY

INTENTIONALLY LEFT BLANK.